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Summary

An experimental investigation of a 19-percent-scale model of the X-31 configuration was completed in the Langley 14- by 22-Foot Subsonic Tunnel. This investigation was performed to determine the static low-speed aerodynamic characteristics of the basic configuration over a large range of angle of attack and sideslip and to study the effects of strakes, leading-edge extensions (wing-body strakes), nose booms, speed-brake deployment, and inlet configurations. The ultimate purpose of this study was to optimize the configuration for high-angle-of-attack and maneuvering-flight conditions. The model was tested at angles of attack from -5° to 67° and at sideslip angles from -16° to 16° for speeds up to 190 knots (dynamic pressure of 120 psf).

The data from this and other preliminary investigations were used to refine the geometry and predict the aerodynamic characteristics for the final full-scale configuration. This was a preliminary investigation to test a wide variety of aerodynamic devices and conditions on an early X-31 configuration. This early configuration deviated somewhat from the current configuration, so some of the data may not be directly applicable to the current full-scale X-31 airplane. This investigation produced a data base on the effects of a large number and combination of strakes, nose booms, leading-edge extensions, and other devices. Selected results are plotted, and the complete data base of tabulated force and moment coefficient data is presented in the appendix. Based on the results from this investigation, the configuration with a low-position nose boom and a midspan fuselage strake was deemed to be the best configuration and was therefore the basis for further testing.

Introduction

The next generation of fighter aircraft will be designed with features allowing controlled flight at extreme attitudes—specifically, at angles of attack that are well above that of maximum lift (post stall). The design of such aircraft requires knowledge of the separated flows that dominate the aerodynamics in this high-angle-of-attack region. The current body of knowledge of such flow fields is somewhat limited. In addition, much of the available knowledge was derived from aircraft that were primarily designed for attached flows (lower angles of attack) and from wind-tunnel tests employing trial-and-error techniques.

In an effort to design an airplane to operate at high-angle-of-attack flight conditions, the Defense Advanced Research Projects Agency (DARPA), in conjunction with the German Ministry of Defense, has funded a project to develop an experimental demonstrator aircraft to investigate the utility of high-angle-of-attack operations. The development of the X-31 has been undertaken in the United States by the Navy, Rockwell International, and NASA and by Messerschmitt-Boelkow-Blohm (MBB) in Germany.

The aerodynamic phenomenon that exists at these extreme attitudes is strongly influenced by the forebody geometry. At high angles of attack, the forebody generates strong vortices that become increasingly influential as the wings and control surfaces become separated and less effective. The vortices that are produced by the forebody eventually, at high enough angles of attack, become asymmetric or burst in an unfavorable location and possibly cause a loss of stability and control. The geometry and surface finish of a forebody can determine where the flow will separate and where vortices will develop.

A strake can fix the position at which the flow separates on a forebody and reduces the previously mentioned sensitivities. A nose boom, however, may make the forebody behave as if it were of a higher fineness ratio. It may also shed vortices onto the nose itself and change the formation, subsequent path, and burst characteristics of the resultant forebody vortices. The path, strength, and burst characteristics of these vortices can alter the flow field of the entire vehicle and can thereby potentially change the overall stability characteristics. Because of this behavior, the forebody geometry and the presence and location of nose booms or flow-altering devices, such as strakes, are of great concern in the design of any aircraft that operates at high angles of attack, such as the X-31.

The X-31 was designed with relaxed pitch stability to obtain increased maneuver performance. In addition, this configuration is equipped with a thrust-vectoring system that should control the vehicle beyond the point where aerodynamic controls alone would be effective.

A wind-tunnel investigation of the proposed X-31 enhanced-maneuverability fighter-aircraft configuration has been completed in the Langley 14- by 22-Foot Subsonic Tunnel. The purpose of the investigation was to determine the high-angle-of-attack aerodynamic characteristics of the proposed configuration and tailor the configuration for optimum maneuver performance when possible. The model is a 19-percent-scale replica of a previous configuration of the X-31, which differed somewhat from the current configuration. The tests were conducted at angles of attack up to 67° and at sideslip angles from -16° to

16° for speeds up to 190 knots (dynamic pressure up to 120 psf). In addition to the study of the stability and control of the basic configuration, the effect of strakes, nose-boom location, inlet condition (flow through, plugged, or augmented), speed-brake deployment (stowed or 50°), and thrust-vectoring paddles (0° or splayed 50° as an additional speed brake) were also investigated at these high-angle-of-attack conditions.

Symbols and Abbreviations

All data have been reduced to standard coefficient form. Longitudinal data are presented in the stability-axis system, and the lateral-directional data are presented in the body-axis system. Computer-generated symbols, where different from the usual notation, are presented after the customary notation in parentheses.

b	reference span, in. or ft
C_A (CAF)	axial-force coefficient, $\frac{\text{Axial force}}{q_\infty S}$
C_D (CD)	drag coefficient, $\frac{\text{Drag}}{q_\infty S}$
C_L (CL)	lift coefficient, $\frac{\text{Lift}}{q_\infty S}$
C_l (CRM)	rolling-moment coefficient, $\frac{\text{Rolling moment}}{q_\infty Sb}$
C_m (CPM)	pitching-moment coefficient, $\frac{\text{Pitching moment}}{q_\infty S\bar{c}}$
C_N (CNF)	normal-force coefficient, $\frac{\text{Normal force}}{q_\infty S}$
C_n (CYM)	yawing-moment coefficient, $\frac{\text{Yawing moment}}{q_\infty Sb}$
C_Y (CSF)	side-force coefficient, $\frac{\text{Side force}}{q_\infty S}$
$\bar{c}$	mean aerodynamic chord, in.
q_∞ (Q)	free-stream dynamic pressure, psf
R	radius, in.
S	reference area, ft^2
α (ALPHA)	angle of attack, deg
β (BETA)	sideslip angle, deg
δ_c	canard deflection (positive leading edge up), deg
$\delta_{f,LE}$	leading-edge flap deflection, denoted inboard/outboard (positive leading-edge down), deg
$\delta_{f,TE}$	trailing-edge elevon deflection, denoted left/right (positive trailing edge down), deg
δ_R	rudder deflection (positive trailing edge right), deg
δ_{SB}	speed-brake deflection (positive trailing edge outboard), deg
δ_{TV}	thrust-vectoring paddle deflection (positive trailing edge outboard), deg

Abbreviations:

AGL	augmented inlet with deflected inlet lip
ALT	alternate-geometry nose, without nose boom
AUG	augmented inlet
BAS	basic-geometry nose, without nose boom
BL	model butt line, in.
BLD	boundary-layer diverter
FS	model fuselage station, in.
FT	flow-through inlet
FTL	flow-through inlet with deflected inlet lip
L1–L4	wing leading-edge configurations and LEX's
LE	leading edge
LEX	leading-edge extensions (wing-body strakes)
MRC	moment reference center (FS = 50.98, WL = −0.380, BL = 0.0)
N1–N7	nose-boom configurations
PLG	plugged inlet (faired external block)
S1–S15	strake configurations
TE	trailing edge
WL	model waterline, in.

Model Description and Test Conditions

The model used in this investigation was a 19-percent-scale model of an early X-31 aircraft configuration. This configuration differed somewhat from the actual full-scale X-31 configuration. A photograph and sketch of the model are presented in figure 1. The wind-tunnel model dimensions are presented in table I. The model construction included a steel inner structure that supported a fiberglass body with aluminum wings, canards, and vertical stabilizer. The model was fabricated with provisions to mount strakes, nose booms, and LEX's in various locations. The model was also equipped with three thrust-vectoring paddles and two deflectable speed brakes. The thrust-vectoring paddles tested in this investigation were either undeflected (0°) or splayed 50° to act as additional speed brakes. The engine inlet was designed as a flow-through duct, which was routed around the balance cavity and exited around the sting-model connection. The inlet could be plugged or the inlet flow could be augmented (increased above flow-through conditions) by using a small ejector at the base of the model. Although this ejector method did not generate a large increase in inlet flow, it was originally thought to be sufficient to identify any significant trends that may develop with changes in inlet flow greater than the flow-through condition. However, this method may not have been sufficient to define these trends. The inlet also incorporated a deflectable lower lip to reduce lip-separation losses at high angles of attack. The inlet lip, when deflected, was tested at 20°.

Various deflections of flaps and control surfaces were tested during this investigation, in addition to strakes, LEX's, and nose booms. The geometric details of these various aerodynamic control surfaces and devices are shown in figure 2. The control surfaces included canards; leading-edge flaps; trailing-edge elevons, which were used in tandem for both lift and pitch control and differentially for roll control; and rudder deflections. Both the leading-edge flaps and elevons were split into two segments and are referred to as inboard and outboard. The leading-edge flaps were used primarily for keeping the wing flow attached (up to higher angles of attack) and not for control. The leading-edge flaps were divided into two segments, inboard and outboard, which were separated at the crank in the wing planform. The elevons were also divided into two segments on each side; however, this was solely for structural considerations and they were always deflected in unison. The inboard section of the leading-edge flap could be deflected to 0°, 20°, and 40°; and the outboard section could be independently deflected to 0°, 16°, and 32°. In general, this type of flap would be scheduled with angle of attack to maintain attached flow on the wing. The deflections of the leading-edge flaps were measured relative to the hinge line (perpendicular), and the deflections of the trailing-edge devices were measured relative to the model waterline. The model also incorporated a remotely controlled canard and a deflectable rudder surface on the vertical stabilizer. The rudder, when deflected, was tested exclusively at 30°. An extended vertical tail (fig. 2(d)) and ventral fins (fig. 2(e)) were also investigated. Deflections of the canard were measured relative to the model waterline, and those of the rudder were measured relative to the hinge line.

Two nose-geometry configurations, referred to as basic and modified, were used during this investigation. Two noses of the basic configuration were constructed; one had provisions to attach strakes and nose booms. This approach was taken to distinguish effects due to the surface condition of the nose, since it was not possible to have both a smooth finish and provisions to attach other devices. The alternate geometry nose was only to be tested with a smooth finish and therefore had no provisions for strakes or booms.

The model was tested at angles of attack from −5° to 67°. To obtain this overall angle-of-attack range with the C-strut support system (ref. 1), two knuckle offsets were used in addition to the straight sting. These three sting configurations provided three overlapping angle-of-attack ranges, which constituted the overall angle-of-attack range. The model was tested at sideslip angles from −16° to 16°. The tunnel velocity was varied up to 190 knots, which corresponds to a free-stream dynamic pressure of 120 psf and a unit Reynolds number of 2×10^6 per foot. The data were corrected for blockage by the classical method (ref. 2) at low angles of attack ($\alpha < 30°$), by a flat-plate empirical method at high angles of attack ($\alpha > 50°$), and with a combination of both methods at intermediate angles of attack ($30° \leq \alpha \leq 50°$).

Presentation of Results

Selected conditions and configurations are presented in the figures. The tabulated force and moment coefficient data for the complete investigation are presented in the appendix. The following list is a general presentation of the figures:

Because the different angle-of-attack ranges overlapped and the leading-edge flap settings were usually set at a nominal position for each angle-of-attack range, each range (low, medium, high) is presented on a separate figure. Best configuration refers to the N6/S12 combination (low-position nose boom with the midspan body strake) and was therefore investigated in more detail.

Discussion of Results

This study was a preliminary investigation of a wide variety of aerodynamic devices and conditions that were used to refine the basic configuration of the X-31 airplane. As such, most configurations and conditions were not investigated in detail and are presented with limited analysis.

Effect of Dynamic Pressure

Dynamic-pressure effects (fig. 3) were investigated to determine the effect of Reynolds number on the aerodynamics of the X-31 configuration and thereby define the appropriate minimum dynamic pressure to be used for most of the testing. The static structural limit of the model imposed a maximum dynamic pressure of 120 psf; however, because of the dynamic loading that was possible with any of the configurations that were slated for testing, it was desirable to conduct most testing at a somewhat lower dynamic pressure.

Effects of dynamic pressure were seen in the longitudinal data (fig. 3(b)) between 5 and 20 psf. Above 20 psf, the effects were much less pronounced. The lateral-directional data show that dynamic-pressure effects were present to some extent throughout the range tested. However, since most of the dynamic-pressure effects settled out by 60 psf, the remainder of the testing was generally conducted at tunnel conditions of 60 psf.

The most noticeable effects due to dynamic pressure were in the high-angle-of-attack, lateral-directional characteristics (figs. 3(d) to 3(f)), and they were most apparent in yawing moment, where they persisted up to the maximum dynamic pressure of 120 psf. The effects seen in yawing moment are most likely the result of vortical flows of the forebody region at high angles of attack. At these angles of attack, the forebody has developed a strong vortex system that may impinge on the empennage and control surfaces and may induce loads on the forebody (mostly caused by the asymmetrically attached flow on the nose caused by the vortices). Because these vortical flows are not steady, the aerodynamic characteristics may be erratic and may display asymmetries at many conditions. Since at higher angles of attack the aerodynamic surfaces are either shielded or the flow about them is separated, the loads induced by the vortices are the dominant loads on the vehicle at these conditions. These unsteady vortical flow fields can be very sensitive to Reynolds number and forebody geometry, including nose booms, so even seemingly small geometric changes may produce relatively large effects.

Effect of Canard Deflection

The effects of canard deflection are presented in figure 4. In general, the effects of canard deflection were as expected—a positive canard incidence produced a small increase in lift with a larger increase in pitching moment up to the point where the canard stalls. Since the wing is operating in the downwash field of the canard, as the canard is loaded the wing unloads somewhat. The dominant effect of increased canard deflection is a forward shift of the center of pressure until the canard stalls. There is an increase in lift with increased canard deflection, and there is an increase in drag that is most noticeable near maximum lift. Because of the characteristics of the canard-wing combination, there are multiple trim points (angles of attack) for a particular canard deflection angle. Since the canard is always operating in relatively undisturbed flow (i.e., there should always be control power available), there should be sufficient pitch control to recover from a stall. This characteristic of a canard is a definite advantage for operations at high angles of attack. Removal of the canard (figs. 4(c) and (d)) also resulted in decreased lift and pitching moment. The configuration with the canard removed was stable up to maximum lift. Then, as expected, it became neutrally stable because, with the canard removed, the center of lift shifts aft relative to the MRC.

Effect of Leading-Edge Flap Deflection

The effects of leading-edge flap deflection are presented in figure 5. The leading-edge flaps are used primarily to keep the upper surface of the wing attached to as high an angle of attack as possible (increased camber and decreased turning angle). On the flight vehicle, the leading-edge flaps would be scheduled with angle of attack to the optimum deflection. The wind-tunnel model was limited to a few discrete settings. In general, the leading-edge flaps produced the desired results within those limitations. At low angles of attack, no noticeable effects due to leading-edge flap deflection resulted (fig. 5(a)). As the angle of attack approaches the value of maximum lift for the undeflected case, the benefit of increased deflection angle extends this angle of attack for maximum lift as well as the level of lift itself (fig. 5(b)). At the higher angles of attack the leading-edge flaps in the deflected position caused no noticeable change in pitch stability or pitching-moment behavior (fig. 5(b)) but did increase lift at higher angles of attack because of the effective increase in camber to the wing.

The lateral-directional characteristics due to leading-edge deflection (figs. 5(c) to 5(g)) show no noticeable effects at lower angles of attack and a slight destabilizing effect at higher angles of attack. These changes in stability occur in yawing moment and rolling moment, but are small in magnitude.

Effect of Elevon Deflection

The effects of elevon deflection are presented in figure 6. The elevons are a multipurpose control surface that can be used for roll control when deflected differentially and pitch control when deflected symmetrically. When deflected symmetrically for pitch control, the elevons act like trailing-edge flaps and change the effective camber of the wing. This change produces a change in lift (figs. 6(a) and 6(b)). In the mid-angle-of-attack range, and presumably in the high-angle-of-attack range, the symmetric elevons also alter the pitch stability, as evidenced by the change in the slope of the pitching-moment curve. Since this configuration can use a variety of combinations of the canard and symmetric elevon to achieve trim at a given angle of attack, the stability and controllability can be tailored to optimize the vehicle performance.

Differential elevon deflections (figs. 6(d) to 6(f)) produced side force, yawing moment, and rolling moment. These forces and moments were most noticeable at the lower angle of attack tested ($\alpha = 30°$), because of the asymmetric camber (left to right) and drag characteristics at sideslip. Symmetric deflections (figs. 6(g) to 6(i)) for pitch control had no noticeable lateral-directional coupling. In general, the effects of elevon deflection were as would be expected on a delta wing planform.

The model was limited to a few discrete elevon settings, both differential and symmetric. Within these limitations, the elevons appear to be capable of generating sufficient levels of rolling moment, pitching moment, and lift.

Effect of Leading-Edge Configuration

The effects of the leading-edge configuration on aerodynamic characteristics are presented in figure 7. Four different leading-edge configurations were investigated. Three were classified as leading-edge extensions, also known as wing-body strakes or LEX's, and the fourth was a sharp leading edge. The sharp leading edge had the effect of increasing pitching moment compared to the basic leading edge at intermediate angles of attack. At low angles of attack, the LEX's tended to produce increased pitching moment without a noticeable increase in lift. At higher angles of attack ($\alpha > 25°$), the LEX configurations (L1 through L3) generated increased lift and pitching moment. (L1 and L2 increased lift the most, followed by L3.) These increases were expected since L1 had the same planform area as L2, but was cambered, and the uncambered L2 had a larger planform area than the uncambered L3. Leading-edge extensions 1, 2, and 3 also caused a decrease in pitch stability.

All LEX configurations produced similar lateral-directional characteristics (figs. 7(c) to 7(e)). The changes in lateral-directional characteristics were minimal, but were most apparent in yawing moment. Very limited data on the sharp leading edge were obtained, and no conclusions could be drawn.

Effect of Nose Geometry, Nose-Boom Configuration, and Location

The effects of nose geometry, nose-boom configuration, and location are presented in figure 8. In general, the effect of nose booms on longitudinal characteristics was slight (fig. 8(a)). The boom configurations with attached strakes (N1 with S4 or S5) produced slightly more lift and pitching moment at higher angles of attack, as would be expected when area is added well forward of the MRC. The effect of the alternate-geometry nose on longitudinal characteristics (fig. 8(b)) was also subtle; the alternate-geometry nose produced slightly more lift than the basic nose above $\alpha = 35°$. The effects of nose booms (figs. 8(d) and 8(e)) and alternate-geometry nose (figs. 8(f) to 8(h)) on lateral-directional characteristics were far more significant. All boom configurations on or close to the nose apex created adverse changes in the already erratic nature of yawing moment at higher angles of attack. These changes are indicative of potentially undesirable dynamic behavior. Other lateral-directional characteristics changed minimally. This undesirable behavior results because the vortical flow field emanates from the boom and then interacts with the flow field on the nose itself. The nose boom in the lowest position

(N6), under the nose, posed the least potential problems and was therefore chosen as the best configuration. Compared with the basic-geometry nose, the alternate-geometry nose created asymmetries in the lateral-directional characteristics and therefore was not investigated further.

Effect of Strake Configuration

The effects of strake configuration are presented in figure 9. The nose strakes (S4 and S6) generated slightly more lift and pitching moment (fig. 9(b)) than the basic configuration in the angle-of-attack region at and beyond maximum lift; however, their main effects were observed in the lateral-directional characteristics (figs. 9(d) to 9(f)) at higher angles of attack, since their major effect was to fix the location of separation on the nose and to contribute relatively little area. Inlet and fuselage strakes generated additional lift and pitching moment and significantly increased maximum lift and the angle of attack for maximum lift in many cases. The forward-fuselage-mounted strakes (S1, S10, S12, and S14) caused a reduction in pitch stability, and the rear-mounted strakes (S2 and S3) caused an increase in pitch stability at higher angles of attack. This effect is expected when area is added in front of or behind the MRC.

In general, nose strakes (S4, S6) caused small increases in directional stability at $\alpha = 30°$ (fig. 9(d)), somewhat larger increases in directional stability (actually a reduction of the instability in directional stability) at $\alpha = 40°$ (fig. 9(e)), and a reduction in yawing moment of about 0.04 at $\alpha = 50°$ and $-12° < \beta < 0°$ (fig. 9(f)). There were relatively small changes in rolling moment and side force caused by the nose strakes at these angles of attack. The fuselage strakes had little effect on side force and rolling moment; however, they produced varied results on yawing moment. Most of the effects on yawing-moment behavior were beneficial—the strakes increased stability and reduced asymmetries. Since it also generated a significant lift increase, the S12 fuselage strake was the most beneficial. Therefore, it became part of the best configuration.

Effect of Inlet Configuration and Condition

The effects of inlet configuration and condition are presented in figure 10. For most of this investigation, a flow-through inlet configuration was used and the exhaust flow exited around the sting at the aft end of the model. The model, however, had a low-pressure ejector at its aft end through which the inlet flow exited. This ejector was used to draw more inlet flow (augment) than that of the flow-through case. This augmented inlet flow was not nearly what would have been needed to scale the mass flow of the inlet, although it was hoped that it would be sufficient to identify any trends caused by increasing mass flow. No significant trends could be identified because of this increase in mass flow. The model was also tested with a blocked or plugged inlet to assess any potential aerodynamic differences from the flow-through case. In addition, the inlet had a deflectable lower lip to reduce turning losses and lip separation at higher angles of attack. There were no significant changes in longitudinal aerodynamic characteristics between the flow-through, plugged, and augmented inlet configurations (figs. 10(a) and 10(b)). In addition, there were no noticeable differences in longitudinal characteristics when a boundary-layer-diverter side plate was added or when the inlet lip was deflected 20°; of course, these devices are designed to increase the performance of the inlet and not the external aerodynamics. The only noticeable longitudinal effect was that the plugged inlet displayed slightly lower lift and pitching moments in the post-stall angle-of-attack range than the unplugged cases. Because the augmented inlet was well below the pressure ratio or mass flow needed to properly scale the actual inlet conditions, since the effect on the longitudinal aerodynamics was very small, no conclusions could be drawn from this result.

There were some noticeable effects on the lateral-directional aerodynamics as a result of the inlet configuration and condition (figs. 10(c) to 10(e)), but most of these effects were small, and no specific trends were identified. The augmented inlet also displayed some deviations in rolling and yawing moments at an angle of attack of 30°, but again these were inconclusive.

Effect of Speed Brakes and Thrust-Vectoring Paddles

The effects of speed brakes and thrust-vectoring paddles are presented in figure 11. As mentioned previously, the thrust-vectoring paddles were only symmetrically deflected outboard ($\delta_{TV} = 50°$) for use as an additional speed-brake device. In addition to the expected increase in drag, deploying the speed brakes alone to 50° caused a reduction in lift and a slight increase in pitching moment. Deploying the thrust-vectoring paddles alone without the speed brakes resulted in a slight increase of maximum lift and a reduction in pitching moment; however, they generated nearly the same amount of drag. In the low-angle-of-attack range there is additional drag being generated by deploying the thrust-vectoring paddles and the speed brakes. Deploying the paddles and the speed brakes above maximum lift caused a decrease in pitching moment but no discernible increase in drag. Since the aft-end fairings are not present on the current configuration, the levels of drag being generated are in question.

The speed brakes and thrust-vectoring paddles had some minor degrading effects on lateral-directional characteristics (figs. 11(c) to 11(e)). At an angle of attack of 30°, deploying the speed brakes caused reductions in the dihedral effect and directional stability, which were worsened by the additional deployment of the thrust-vectoring paddles. These effects were reduced at an angle of attack of 40°. There were changes in yawing moment at an angle of attack of 50° due to the deflection of the speed brakes, but these effects did not appear to be detrimental; there were no significant additional effects from the deflection of the thrust-vectoring paddles.

Effect of Rudder Deflection, Large Vertical Tail, and Ventral Fins

The effects of rudder deflection, large vertical tail, and ventral fins are presented in figure 12. Only one rudder deflection (30°) was tested in addition to the undeflected case. At an angle of attack of 30°, the rudder generated significant levels of yawing moment and associated side force and rolling moment as expected. The level of yawing moment was reduced at an angle of attack of 40° and further reduced at 50°, as expected. The vertical extension and ventral fin each increased directional stability; the ventral fin became relatively more powerful at higher angles of attack, as expected, since the tail became increasingly shielded.

Configuration With N6 Boom, and S12 Strake

Results from the final or best configuration are presented in figure 13. This configuration, with the N6 boom (mounted below the nose) and the S12 strake (midspan fuselage strake), had the best overall characteristics. The longitudinal results (figs. 13(a) to 13(c)) indicate that the configuration has a maximum trimmed lift coefficient of approximately 1.15 and appears to be trimmable throughout the angle-of-attack range tested (based on the discrete canard settings). Further, it appears that a canard deflection of approximately −40° would be sufficient to provide minimum trim capability.

The lateral-directional results (figs. 13(d) to 13(h)) indicate that, in general, the configuration is well behaved up to an angle of attack of 60° with $\delta_c = -20°$. There was a reversal in directional stability between angles of attack of 30° and 40° and at high sideslip angles ($\beta > 4°$). The directional stability characteristics were less well behaved above an angle of attack of 40° in that they were nonlinear but not erratic. There was a reduction in the dihedral effect up to an angle of attack of 50° and no further reduction up to 65°. Although the addition of the refueling boom reduced directional stability, it had no severe detrimental impact on the lateral-directional characteristics up through these high angles of attack.

Summary of Results

An investigation of the low-speed static longitudinal and lateral-directional aerodynamic characteristics of an early version of the X-31 configuration has been completed. The results from this investigation were used to define the configuration in further detail. The following results summarize the findings of this investigation:

1. The configuration with the boom mounted below the nose (N6) and with a midspan fuselage strake (S12) had the best overall aerodynamic characteristics.

2. The configuration displayed adequate levels of stability and control authority throughout the range of conditions tested. At higher angles of attack, yawing moment was erratic in many instances because of the separated (vortical) flow field of the forebody.

3. The position of the nose boom and presence of forebody strakes had a significant impact on lateral-directional aerodynamic characteristics at high angles of attack. This impact is a result of the dominance of the forebody flow field under these conditions.

4. Reynolds number effects were significant at high angles of attack. These effects were most noticeable on the lateral-directional behavior.

5. The addition of a refueling boom on the final configuration had no significant effect on lateral-directional characteristics.

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July 9, 1992

References

1. Gentry, Garl L., Jr.; Quinto, P. Frank; Gatlin, Gregory M.; and Applin, Zachary T.: *The Langley 14- by 22-Foot Subsonic Tunnel: Description, Flow Characteristics, and Guide for Users.* NASA TP-3008, 1990.

2. Rae, William H., Jr.; and Pope, Alan: *Low-Speed Wind Tunnel Testing*, Second ed. John Wiley & Sons, Inc., c.1984.

Appendix

Test Conditions and Acquired Data

This investigation covered a wide range of configurations and conditions. This appendix contains a complete list of the acquired data, except those data points that were found to be in error. A detailed list of the nominal test configurations and conditions are presented in table A1. A complete set of tabulated data is presented in table A2.

The angle-of-attack schedules (A1–A8), sideslip schedule (B1), and canard deflection schedules (C1–C2) referred to in table A1, are as shown below:

A1: $-5°$, $0°$, $5°$, $10°$, $15°$, $20°$, $21°$, $22°$, $23°$, $24°$, $25°$, $26°$, $27°$, $28°$, $29°$, $30°$

A2: $-5°$, $0°$, $5°$, $10°$, $15°$, $20°$, $21°$, $22°$, $23°$, $24°$, $25°$, $26°$, $27°$, $28°$, $29°$, $30°$, $31°$, $32°$

A3: $-5°$, $0°$, $5°$, $10°$, $15°$, $20°$, $21°$, $22°$, $23°$, $24°$, $25°$, $30°$, $32°$

A4: $17°$, $20°$, $25°$, $26°$, $27°$, $28°$, $29°$, $30°$, $31°$, $32°$, $33°$, $34°$, $35°$, $40°$, $45°$, $50°$, $55°$

A5: $17°$, $20°$, $25°$, $30°$, $35°$, $40°$, $45°$, $50°$, $55°$, $57°$

A6: $17°$, $20°$, $25°$, $30°$, $32°$, $35°$, $40°$, $45°$, $50°$, $55°$, $57°$

A7: $28°$, $30°$, $32°$, $34°$, $35°$, $37°$, $40°$, $45°$, $50°$, $55°$, $60°$, $65°$, $67°$

A8: $45°$, $50°$, $55°$, $60°$, $65°$, $67°$

B1: $-16°$, $-12°$, $-8°$, $-4°$, $0°$, $4°$, $8°$, $12°$, $16°$

C1: $20°$, $10°$, $0°$, $-10°$, $-20°$, $-30°$, $-40°$, $-50°$, $-60°$

C2: $-20°$, $-25°$, $-30°$, $-35°$, $-40°$, $-45°$, $-50°$, $-55°$, $-50°$, $-65°$, $-60°$, $-60°$

Table 1. Model Dimensions

Length (basic configuration), ft	8.23
Wing span, ft	4.338
Wing aspect ratio	2.3 0
Mean aerodynamic chord, ft	2.2 63
Wing reference area, ft^2	8.16 7
Wing thickness ratio, percent	5.5
Wing leading-edge sweep (inboard), deg	56.6
Wing leading-edge sweep (outboard), deg	45.0
Wing trailing-edge sweep, deg	−5.858
Canard aspect ratio	3.18
Canard reference area, ft^2	8. 962
Canard thickness ratio, percent	5.0
Canard leading-edge sweep, deg	45.0
Canard trailing-edge sweep, deg	6.057
Tail aspect ratio	1.23
Tail reference area, ft^2	1.357
Tail thickness ratio, percent	5.0
Tail leading-edge sweep, deg	50

L-92-27

(a) Model positioned in Langley 14- by 22-Foot Subsonic Tunnel.

Figure 1. The 19-percent scale X-31 model.

(b) Three-view sketch of model.

Figure 1. Concluded.

(a) Wing planform.

Figure 2. Detailed geometry of selected model components. All linear dimensions are in inches; not to scale.

(b) Canard.

Figure 2. Continued.

(c) Vertical tail and rudder.

(d) Large vertical extension.

Figure 2. Continued.

(e) Ventral fins.

(f) Sharp leading edge L4.

Figure 2. Continued.

(g) Leading-edge extensions (LEX).

Figure 2. Continued.

(h) Nose booms.

Figure 2. Continued.

(h) Concluded.

Figure 2. Continued.

(i) Refueling boom (N7).

Figure 2. Continued.

(j) Nose strakes.

Figure 2. Continued.

(k) Inlet strakes.

Figure 2. Continued.

(k) Concluded.

Figure 2. Continued.

(l) Fuselage strakes.

Figure 2. Continued.

(l) Concluded.

Figure 2. Continued.

(m) Aft fuselage strake.

Figure 2. Concluded.

(a) Low-angle-of-attack range; $\delta_c = -20°$; $\delta_{f,LE} = 0°/0°$.

Figure 3. Effect of dynamic pressure on aerodynamic characteristics. $\delta_{f,TE} = 0°/0°$; $\delta_R = 0°$; $\delta_{TV} = 0°$; $\delta_{SB} = 0°$; flow-through inlet; basic nose; no strakes; basic leading edge.

(b) Medium-angle-of-attack range; $\beta = 0°$; $\delta_c = -20°$; $\delta_{f,LE} = 40°/32°$.

Figure 3. Continued.

(c) High-angle-of-attack range; $\beta = 0°$; $\delta_c = -60°$; $\delta_{f,LE} = 40°/32°$.

Figure 3. Continued.

(d) $\alpha = 60°$; $\delta_c = -60°$; $\delta_{f,LE} = 40°/32°$.

Figure 3. Continued.

(e) $\alpha = 65°$; $\delta_c = -60°$; $\delta_{f,LE} = 40°/32°$.

Figure 3. Continued.

(f) $\alpha = 67°$; $\delta_c = -60°$; $\delta_{f,LE} = 40°/32°$.

Figure 3. Concluded.

(a) Low-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 0°/0°$.

Figure 4. Effect of canard deflection angle on aerodynamic characteristics. $q_\infty = 60$ psf; $\delta_{f,TE} = 0°/0°$; $\delta_R = 0°$; $\delta_{TV} = 0°$; $\delta_{SB} = 0°$; flow-through inlet; basic nose; no strakes; basic leading edge.

(b) Medium-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 0°/0°$.

Figure 4. Continued.

(c) Medium-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 40°/32°$.

Figure 4. Continued.

(d) High-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 40°/32°$.

Figure 4. Concluded.

(a) Low-angle-of-attack range; $\delta_c = -20°$; $\beta = 0°$.

Figure 5. Effect of leading-edge flap deflection on aerodynamic characteristics. $q_\infty = 60$ psf; $\delta_{f,TE} = 0°/0°$; $\delta_R = 0°$; $\delta_{TV} = 0°$; $\delta_{SB} = 0°$; flow-through inlet; basic nose; no strakes.

(b) Medium-angle-of-attack range; $\beta = 0°$; $\delta_c = -40°$.

Figure 5. Continued.

(c) $\alpha = 20°$; $\delta_c = -20°$.

Figure 5. Continued.

(d) $\alpha = 30°$; $\delta_c = -20°$.

Figure 5. Continued.

(e) $\alpha = 40°$; $\delta_c = -20°$.

Figure 5. Continued.

(f) $\alpha = 50°$; $\delta_c = -20°$.

Figure 5. Continued.

(g) $\alpha = 55°$; $\delta_c = -20°$.

Figure 5. Concluded.

(a) Low-angle-of-attack range; $\beta = 0°$; $\delta_c = -20°$.

Figure 6. Effect of elevon deflection on aerodynamic characteristics. $q_\infty = 60$ psf; $\delta_{f,LE} = 40°/32°$; $\delta_R = 0°$; $\delta_{TV} = 0°$; $\delta_{SB} = 0°$; flow-through inlet; basic nose; no strakes.

(b) Medium-angle-of-attack range; $\beta = 0°$; $\delta_c = -40°$.

Figure 6. Continued.

(c) Medium-angle-of-attack range; $\beta = 0°$; $\delta_c = -20°$.

Figure 6. Continued.

(d) $\alpha = 30°$; $\delta_c = -20°$.

Figure 6. Continued.

(e) $\alpha = 40°$; $\delta_c = -20°$.

Figure 6. Continued.

(f) $\alpha = 50°$; $\delta_c = -20°$.

Figure 6. Continued.

(g) $\alpha = 30°$; $\delta_c = -20°$.

Figure 6. Continued.

(h) $\alpha = 40°$; $\delta_c = -20°$.

Figure 6. Continued.

(i) $\alpha = 50°$; $\delta_c = -20°$.

Figure 6. Concluded.

(a) Low-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 20°/16°$; $\delta_{TV} = 0°$.

Figure 7. Effect of leading-edge configuration on aerodynamic characteristics. $q_\infty = 60$ psf; $\delta_c = -20°$; $\delta_{f,TE} = 0°/0°$; $\delta_R = 0°$; $\delta_{SB} = 0°$; flow-through inlet; basic nose; no strakes.

(b) Medium-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 40°/32°$; $\delta_{TV} = 0°$.

Figure 7. Continued.

(c) $\alpha = 30°$; $\delta_{f,LE} = 40°/32°$.

Figure 7. Continued.

(d) $\alpha = 40°$; $\delta_{f,LE} = 40°/32°$.

Figure 7. Continued.

(e) $\alpha = 50°$; $\delta_{f,LE} = 40°/32°$.

Figure 7. Concluded.

(a) Medium-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 40°/32°$.

Figure 8. Effect of nose geometry and nose boom configuration on aerodynamic characteristics. $q_\infty = 60$ psf; $\delta_c = -20°$; $\delta_{f,TE} = 0°/0°$; $\delta_R = 0°$; $\delta_{TV} = 0°$; $\delta_{SB} = 0°$; flow-through inlet; no strakes.

(b) Low-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 40°/32°$.

Figure 8. Continued.

(c) Medium-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 40°/32°$.

Figure 8. Continued.

(d) $\alpha = 30°$; $\delta_{f,LE} = 40°/32°$.

Figure 8. Continued.

(e) $\alpha = 40°$; $\delta_{f,LE} = 40°/32°$.

Figure 8. Continued.

(f) $\alpha = 50°$; $\delta_{f,LE} = 40°/32°$.

Figure 8. Continued.

(g) $\alpha = 30°$; $\delta_{f,LE} = 0°/0°$.

Figure 8. Continued.

(h) $\alpha = 40°$; $\delta_{f,LE} = 0°/0°$.

Figure 8. Continued.

(i) $\alpha = 50°$; $\delta_{f,LE} = 0°/0°$.

Figure 8. Concluded.

(a) Low-angle-of-attack range; $\beta = 0°$.

Figure 9. Effect of strake configuration on aerodynamic characteristics. $q_\infty = 60$ psf; $\delta_c = -20°$; $\delta_{f,LE} = 40°/32°$; $\delta_{f,TE} = 0°/0°$; $\delta_R = 0°$; $\delta_{TV} = 0°$; $\delta_{SB} = 0°$; flow-through inlet; basic nose.

(b) Medium-angle-of-attack range; $\beta = 0°$.

Figure 9. Continued.

(c) Medium-angle-of-attack range; $\beta = 0°$.

Figure 9. Continued.

(d) $\alpha = 30°$.

Figure 9. Continued.

(e) $\alpha = 40°$.

Figure 9. Continued.

(f) $\alpha = 50°$.

Figure 9. Concluded.

(a) Low-angle-of-attack range; $\beta = 0°$.

Figure 10. Effect of inlet configuration and condition on aerodynamic characteristics. $q_\infty = 60$ psf; $\delta_c = -20°$; $\delta_{f,LE} = 40°/32°$; $\delta_{f,TE} = 0°/0°$; $\delta_R = 0°$; $\delta_{TV} = 0°$; $\delta_{SB} = 0°$; basic nose; no strakes.

(b) Medium-angle-of-attack range; $\beta = 0°$.

Figure 10. Continued.

(c) $\alpha = 30°$.

Figure 10. Continued.

(d) $\alpha = 40°$.

Figure 10. Continued.

(e) $\alpha = 50°$.

Figure 10. Concluded.

(a) Low-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 0°/0°$.

Figure 11. Effect of speed brake and thrust-vectoring-paddle deflection on aerodynamic characteristics. $q_\infty = 60$ psf; $\delta_c = -20°$; $\delta_{f,TE} = 0°/0°$; $\delta_R = 0°$; flow-through inlet; basic nose; no strakes.

(b) Medium-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 40°/32°$.

Figure 11. Continued.

(c) $\alpha = 30°$; $\delta_{f,LE} = 40°/32°$.

Figure 11. Continued.

(d) $\alpha = 40°$; $\delta_{f,LE} = 40°/32°$.

Figure 11. Continued.

(e) $\alpha = 50°$; $\delta_{f,LE} = 40°/32°$.

Figure 11. Concluded.

(a) $\alpha = 30°$.

Figure 12. Effect of enlarged vertical tail, ventral fins, and rudder deflection on aerodynamic characteristics. $q_\infty = 60$ psf; $\delta_c = -20°$; $\delta_{f,LE} = 40°/32°$; $\delta_{f,TE} = 0°/0°$; $\delta_{TV} = 0°$; $\delta_{SB} = 0°$; flow-through inlet; basic nose; no strakes.

(b) $\alpha = 40°$.

Figure 12. Continued.

(c) $\alpha = 50°$.

Figure 12. Concluded.

(a) Low-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 0°/0°$.

Figure 13. Combined effect of N6 boom and S12 strake configuration on aerodynamic characteristics. $q_\infty = 60$ psf; $\delta_{f,TE} = 0°/0°$; $\delta_R = 0°$; $\delta_{TV} = 0°$; $\delta_{SB} = 0°$; flow-through inlet.

(b) Medium-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 40°/32°$.

Figure 13. Continued.

(c) High-angle-of-attack range; $\beta = 0°$; $\delta_{f,LE} = 0°/0°$.

Figure 13. Continued.

(d) $\alpha = 30°$; $\delta_c = -20°$; $\delta_{f,LE} = 40°/32°$.

Figure 13. Continued.

(e) $\alpha = 40°$; $\delta_c = -20°$; $\delta_{f,LE} = 40°/32°$.

Figure 13. Continued.

(f) $\alpha = 50°$; $\delta_c = -20°$; $\delta_{f,LE} = 40°/32°$.

Figure 13. Continued.

(g) $\alpha = 60°$; $\delta_c = -20°$; $\delta_{f,LE} = 40°/32°$.

Figure 13. Continued.

(h) $\alpha = 65°$; $\delta_c = -20°$; $\delta_{f,LE} = 40°/32°$.

Figure 13. Concluded.